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TRADE-OFF ANALYSIS OF PROPULSION SYSTEMS FOR SUBMERSIBLES (TAPS--ETC(U)
JUL 78 R S PETERSON
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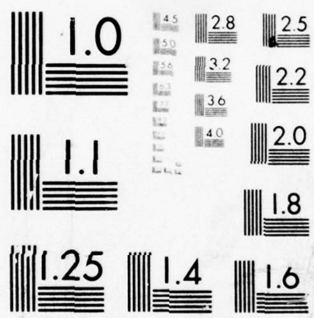


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TECHNICAL
MEMORANDUM
NCSC TM232-78

JULY 1978

# TRADE-OFF ANALYSIS OF PROPULSION SYSTEMS FOR SUBMERSIBLES (TAPSS)





R. S. PETERSON



NAVAL COASTAL SYSTEMS CENTER
NCSC
PANAMA CITY, FLORIDA 32407

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**NAVAL COASTAL SYSTEMS CENTER**

**PANAMA CITY, FLORIDA 32407**

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Commanding Officer

GERALD G. GOULD
Technical Director

## ADMINISTRATIVE INFORMATION

Investigation and computer program implementation were accomplished under Task Area Number SF 411 213, Program Element Number 62543N, Work Unit Number 20810, and Task Area Number SF 34 371 491, Program Element Number 62374, Work Unit Number 20298.

Released by
Douglas E. Humphreys, Head
Hydrodynamics Division
July 1978

Under Authority of
M. J. Wynn, Head
Coastal Technology Department

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Trade off analysis; Submersibles; Underwater vehicles; Propulsion system integration; Computerized simulation; Drag; Costs; Design

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report documents Trade-off Analysis of Propulsion Systems for Submersibles (TAPSS), a FORTRAN computer program designed to aid in optimizing the size, cost, and performance of a preprogrammed, dry, underwater vehicle by performing propulsion-related parameter trade-offs. The program calculates engine power, vehicle size, and approximate cost as a function of input speeds and endurance to facilitate the examination of vehicle configurations and their capability to fulfill mission requirements. The program will assist in the conceptual optimization of the system configuration.

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10.

Task Area No. SF 34 371 491
Program Element No. 62374
Work Unit No. 20298

19.
Identifiers:
TAPSS (Trade off Analysis of Propulsion System for Submersibles)



S/N 0102-LF-014-6601

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## TABLE OF CONTENTS



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## INTRODUCTION

Mines are one of the most severe and fastest growing threats to U.S. security. A program was initiated by the Navy to develop the mission requirements, system characteristics, and technology ncesssary for a remotely controlled or preprogrammed, self-propelled, submerged, mine countermeasures (MCM) vehicle. The exact vehicle mission has not yet been established. Thus, performance and mission parameters such as speed, endurance, vehicle configuration, payload, sensor, and neutralization capability are undefined. To define a reasonable range of mission requirements, the relative effect of many such parameters must be examined through a trade-off analysis. The analysis becomes iterative, because the resulting range of mission requirements are used as input to the trade-off analysis for additional refinement of system parameters.

Because of the large number of factors involved, computerized performance of the trade-off analysis is most effective. A FORTRAN computer program Trade-off Analysis of Propulsion Systems for Submersibles (TAPSS), was developed to examine a wide variety of vehicle propulsion systems. TAPSS supersedes an earlier program written in BASIC, which was documented in an NCSL unpublished document[1]. Although the two programs use a similar approach in performing the trade-off analysis, TAPSS has expanded capabilities, including (1) use of FORTRAN, a more universal and powerful language, (2) an accurate drag calculation to account for laminar and transition flow (in addition to turbulent), and surface roughness and protuberances, (3) cruise and dash mission speed input, (4) accurate, nonlinear relationships relating volume to performance and payload type, (5) complete versatility in combining types of engines and fuel systems, (6) a component weight calculation to check and correct for neutral buoyancy, and (7) an accurate hull structure algorithm which accounts for the strength and elastic stability of both the shell and rib stiffeners.

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[1]Naval Coastal Systems Laboratory Technical Note TN396, *Computer-Aided Trade-off Analysis of Submerged Minehunting Vehicle Systems*, by R. S. Peterson, April 1977.

## PROGRAM DESCRIPTION

TAPSS calculates vehicle power, size, and dollar cost as a function of mission (total endurance, dash speed, cruise speed, and percent cruise time), engine type, fuel system type, component densities, vehicle geometry, and numerous functions relating to cost, performance, and volume. The calculation scheme is iterative. The program assumes an initial estimate for vehicle size and calculates the corresponding drag coefficients and power required to propel the vehicle at the specified speeds. The program then calculates engine volume and fuel volume needed to meet the endurance requirement. The vehicle is scaled up or down to accommodate the resulting change in volume from the original assumed value. New drag coefficients are calculated, and the process is repeated until the volume change becomes small. When the calculation converges, the resulting power, size, and cost are printed out.

The basic layout for the MCM vehicle is presented in Figure 1. The position and sizes shown for the various subsystems are arbitrary and intended only to illustrate the volume build-up scheme.

## INPUT AND OUTPUT

The following input is required for TAPSS:

1. A set of 40 volume functions.

2. A set of options to identify engine type, physical state and type of fuel, oxidizer state, type of battery, and technology time frame.

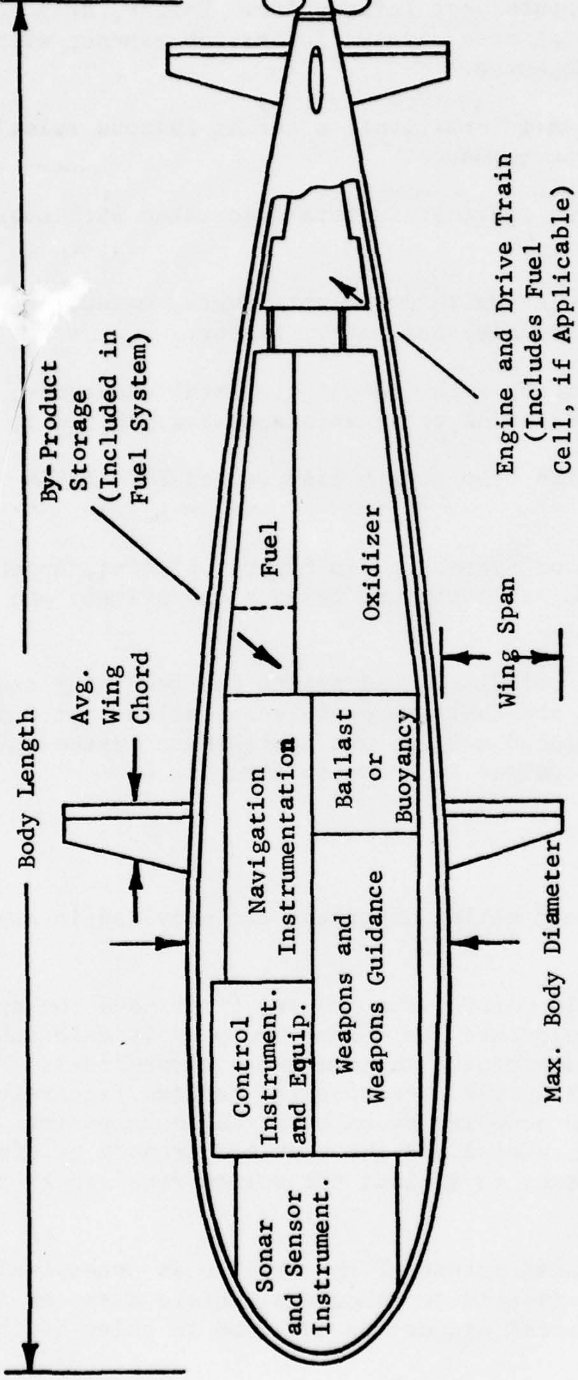
3. Miscellaneous information, including propeller efficiency, fuel/oxidizer mass ratios for hydrocarbon and hydrogen, instrumentation power requirements and seawater temperature.

4. Wing information: a number of equally sized control surfaces and, for each, a thickness to chord, chord to body length, and span to chord ratio.

5. Axisymmetric body information: prismatic coefficient, length to diameter ratio, nondimensional wetted area, and hull volume packing efficiency.

6. Volume information: a total internal volume estimate to initiate the calculation; fixed payload volumes for navigation, sensor, and mine neutralization instrumentation and equipment; and a control instrumentation sizing factor.

(Text Continued on Page 4)




Note: For vehicle shown, No. of wings = 8.

FIGURE 1. MCM VEHICLE BASIC LAYOUT, NTS

7. Roughness and protuberance information: height, drag coefficient, and fraction of total area covered for protuberances; average grain size in mils for roughness.

8. Weight calculation information: a set of factors relating component weight to size or performance.

9. A set of densities and cost factors associated with subsystem size and performance.

10. Hull weight calculation information: depth, material modulus of elasticity and yield strength, and safety factor.

11. A series of missions, each including a total endurance, cruise speed, dash speed, and percent of total endurance the vehicle is cruising.

These data are read by TAPSS from a data file called TAPSS/DATA (Appendix A).

The 40 sizing functions (presented in Program Listing, Appendix B) were derived from a search of literature in both the private and government sectors.

The computer program calculates and prints out resulting cruise power, dash power, engine and fuel system volumes, ballast or buoyancy, vehicle diameter and displaced weight, and approximate system unit construction cost. A sample output is shown in Appendix C.

## CALCULATION SCHEME

The program listing and sizing algorithm are provided in Appendices B and D.

In determining vehicle volume, the program first uses the appropriate volume functions to calculate the volume occupied by each subsystem component (based on the component's maximum outer dimensions). Next, the volume is increased using the corresponding packing factor function to give the vehicle volume occupied by each installed component. The installed volumes are then summed and the result increased by dividing by the hull volume efficiency to include the volume required by the hull and other structures.

Once the total displaced volume of the vehicle is determined, vehicle shape information is used to calculate vehicle diameter and surface area. Depth and material properties are used to calculate hull

thickness, weight, and spacing of stiffeners[2]. Next, mission speeds are used to establish the drag and horsepower values and, consequently, engine size. Horsepower and endurance are used in determining fuel system size. The resulting engine and fuel volumes are added to the original estimate, yielding a modified vehicle diameter. The drag calculation, and engine and fuel system sizing are repeated, and the iteration is continued until it converges.

There are several important assumptions involved in the sizing calculation. A volume-limited vehicle is initially assumed; that is, the size of the vehicle is determined by individual component volumes, not component weights. When the calculation converges on a final volume, the difference between the vehicle weight in air and the vehicle displaced weight is determined. Neutral buoyancy is achieved by adding the necessary ballast (which is not allowed to affect the volume) or the necessary air volume (which is not allowed to affect the weight). In the latter case, the vehicle sizing calculation must be reentered. The calculation quickly converges upon a vehicle meeting both volume and neutral buoyancy criteria.

## DRAG CALCULATION

The drag of an underwater vehicle is a function of many variables, including velocity, temperature (viscosity), surface area, surface condition, protuberances, control surfaces, body fineness, and the type of flow (laminar, transition or turbulent). If the flow is fully turbulent and the body smooth, the drag coefficient may be calculated easily with a high degree of accuracy. At low speeds, however, there is a possibility of laminar or transition flow, particularly on the wings. In addition, roughness and protuberances are always present. Although not easily calculated, the contribution of such effects can be appreciable and should not be ignored in propulsion system-sizing calculations.

Table 1 illustrates the TAPSS drag calculation method. Four Reynolds numbers, corresponding to the dash and cruise speed for the wing and body, are calculated. Drag due to lift is neglected. Each of the four cases is directed into laminar, transition, or turbulent flow drag calculations. If laminar, the theoretical Blasius solution[3] for smooth skin friction

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[2] Faires, V. M., *Design of Machine Elements,* The MacMillan Co., 1971, p. 523.

[3] Hoerner, S. F., *Fluid Dynamic Drag,* published by the author, 1965, pp. 2-4 and 5-3.

(Text Continued on Page 7)

TABLE 1

DRAG CALCULATION

| Drag | Body (Cruise and Drag) | | Wing (Cruise and Drag) | | |
|---|---|---|---|---|---|
| | Transition | Turbulent | Laminar | Transition | Turbulent |
| CFBAS<br>Smooth Skin Friction | Schlicting<br>$0.455/(\log R)^{2.58} - A/R$ | | Blasius<br>$1.328/\sqrt{R}$ | Schlicting<br>$0.455/(\log R)^{2.58} - A/R$ | |
| CFRUF<br>Roughness Contribution | Curve Fit to<br>Hoerner (p. 5-1) | | CFRUF = 0 | Curve Fit to<br>Hoerner (p. 5-1) | |
| CFPRT<br>Protuberance Contribution | CFPRT = 0 | Hoerner (p. 5-7)<br>$1.32(FPRT)(CD)\left(\frac{h}{L}\right)^{1/3}(R)^{0.067}$ | CFPRT = 0 | Hoerner (p. 5-7)<br>$1.32(FPRT)(CD)\left(\frac{h}{L}\right)^{1/3}(R)^{0.067}$ | |
| CF<br>Total Skin Friction | Sum for Relative Contribution (RPCB) | Sum for CF | CFBAS | Sum for Relative Contribution (RPCW) | Sum for CF |
| CD<br>Total Drag Coefficient | Curve Fit Hoerner (p. 6-16) x RPCB | Hoerner Eqn. 28 (p. 6-17) | Hoerner Eqn. 2 (p. 6-5) | Curve Fit Hoerner (p. 6-2) x RPCW | Hoerner Eqn. 6 (p. 6-6) |

is used. If the flow is turbulent or in the transition region, a modification of the empirical Schoenherr relation[4] is used to calculate smooth skin friction.

The contribution of roughness to the skin friction is established as a function of relative grain size ($k/\ell$) where k is a representative sand grain diameter and $\ell$ is the body length or wing chord. A table relating relative grain size to typical surfaces is provided by Hoerner[3]. Hoerner constructed a set of experimental data showing the contribution of roughness to the modified Schoenherr smooth skin friction, as a function of Reynolds number and relative grain size (Hoerner, p. 5-1)[3]. An analytical expression was derived to reproduce the experimental data for use in TAPSS.

To establish the contribution of protuberances (such as rivets) to smooth skin friction, a technique presented by Hoerner (p. 5-7)[3] was modified. The resulting expression gives the contribution due to protuberances as a function of Reynolds number, specific drag coefficient, relative height of the protuberance, and fraction of total area covered by the protuberances. In each case, the total skin friction is calculated as the sum of its individual components. The combined skin friction value is used in the body/turbulent total drag calculation and in the wing/turbulent and wing/laminar calculation. For the body/transition and wing/transition total drag calculation, two factors are calculated which represent the ratio of total skin friction to the smooth skin friction (RPCB and RPCW, Roughness and Protuberance Contribution for Body and for Wing, respectively).

The total drag coefficient, based on wetted area, must account for shape form drag and thus is a function of the length to diameter ratio. As body flow is not likely to be laminar, this case is neglected. A rough curve fit to data given in Hoerner (p. 6-16)[3] was developed to calculate body total drag in transition. Since these data give the total drag coefficient for a smooth surface, it is necessary to multiply the drag by the factor (RPCB) determined in the skin friction calculation. For the body/turbulent case, Hoerner gives an equation relating the total drag to the skin friction (Hoerner, p. 6-17)[3]. The skin friction used in this expression is the sum of the individual contributions described previously.

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[3]ibid.

[4]Schlicting, F., *Boundary Layer Theory*, McGraw-Hill Book Company, 1968, p. 602.

The total drag coefficient for the wing is determined for any of the three types of flow. In cold water, a small wing at low speed would likely encounter laminar flow. In this case, Hoerner supplies an equation for the total drag as a function of skin friction (Hoerner, p. 6-5)[3]. The skin friction value reflects the contribution of roughness and protuberances. Hoerner provides a similar expression for wing turbulent flow (Hoerner, p. 6-6)[3] which is used in a like manner. For the transition case, however, Hoerner presents only experimental data giving the total drag coefficient for smooth wings as a function of thickness to chord (Hoerner, p. 6-2)[3]. An analytical expression was derived which fits these data. The resulting drag is multiplied by the factor RPCW, determined in the skin friction calculation.

The entire drag calculation is performed for both the cruise and the dash speeds. In each case the total drag coefficients calculated for the wing and body are multiplied by their respective wetted areas, summed, and multiplied by $\frac{1}{2} \rho V^2$ to yield the resulting drag force.

## SUMMARY AND RECOMMENDATIONS

TAPSS, a FORTRAN computer program, was developed to calculate the power, size, and approximate cost of small, dry submersibles as a function of speed, endurance, and a group of input parameters and functions. This program enables the user to examine a wide range of vehicle configurations and missions.

The user should be aware of the simplifying assumptions used in the analysis. The three most important assumptions in the sizing algorithm involve the drag calculation accuracy, shape limitations, and volume function accuracy. In the case of the drag algorithm, it is impossible to predict precisely the transition from laminar to turbulent flow, and the drag contribution of protuberances and roughness. In the case of shapes, situations could exist where the specified component would not fit into the vehicle, even though the various volumes sum correctly. For instance, suppose the program determines that, for a given mission and set of input parameters, a 2-foot diameter vehicle requires 3 cubic feet of electric motor. This would pose a problem if the required off-the-shelf motor has a diameter approaching 2 feet. Finally, the accuracy of the results is limited by the accuracy of the volume functions. These functions should be updated with improving technology and additional information.

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[3] ibid.

The vehicle size predicted by TAPSS is only an estimate. The absolute size should therefore be used only in the preliminary design stage.

TAPSS should be used principally for two functions. First, the program can assist in defining a reasonable set of mission requirements, given cost, and technology limitations. Second, once the mission is narrowed, the program can expeditiously minimize cost and size or maximize performance by manipulating vehicle geometry, payload, and propulsion system parameters. Analysis of the resulting matrix of vehicles will lead to a preliminary, optimum configuration. TAPSS exhibits much greater accuracy in performing the latter function, because the relative effect of changes in subsystem parameters can be more reliably assessed than the absolute size corresponding to one set of subsystem parameters.

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APPENDIX A

TAPSS INPUT DATA RECORD DESCRIPTION

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| FILE | RECORD | INPUT VARIABLE | | | | |
|---|---|---|---|---|---|---|
| | | NAME | VALUE | FORMAT | DESCRIPTION | REMARKS |
| TAPSS/ DATA | 0 | TITLE | As Input | 18A4 | 72-character alphanumeric problem identifier | |
| | 1 | IENG | 1 | I10 | DC motor and fuel cell | Records 1 and 2 specify a set of eight program options which identify engine type, fuel physical state and type, diluent, combustor type, oxidizer state, battery type, and technology time frame. |
| | | | 2 | I10 | DC motor and battery | |
| | | | 3 | I10 | Internal combustion engine, closed cycle | |
| | | | 4 | I10 | Closed Brayton cycle engine | |
| | | IFUEL | 1 | I10 | Hydrocarbon | |
| | | | 2 | I10 | Hydrogen, 3000 psi gaseous | |
| | | | 3 | I10 | Hydrogen, liquid | |
| | | | 4 | I10 | Hydrogen, metal matrix | |
| | | IDILU | 1 | I10 | Air diluted hydrocarbon | When an entry is not applicable, its value is arbitrary. |
| | | | 2 | I10 | Helium diluted hydrocarbon | |
| | | ICOMB | 1 | I10 | LISF6 (lithium sulfurhexafluoride) combustor | |
| | | | 2 | I10 | Carbon block combustor | |
| | | IOXID | 1 | I10 | Oxygen, 3000 psi gaseous | |
| | | | 2 | I10 | Oxygen, liquid | |
| | 2 | IBATT | 1 | I10 | Lithium inorganic battery | |
| | | | 2 | I10 | Silver zinc battery | |
| | | ITIME | 1 | I10 | 1980 technology | |
| | | | 2 | I10 | 1985 technology | |
| | | | 3 | I10 | 1990 technology | |
| | | IEXT | 1 | I10 | Standard program output | |
| | | | 2 | I10 | Extended output for values of intermediate answers | |
| | 3 | EPROP | As Input | F10 | Propeller efficiency | |
| | | RHC | As Input | F10 | Fuel to oxidizer weight ratio for hydrocarbon | |
| | | RHD | As Input | F10 | Fuel to oxidizer weight ratio for hydrogen | |
| | | PINST | As Input | F10 | Power for instrumentation and overhead; in kw | |
| | | TEMPF | As Input | F10 | Seawater temperature in °F | This value impacts vehicle drag. |
| | 4 | NEND | As Input | I10 | Number of endurance values | The total number of missions examined will be NEND X NSPD. |
| | | NSPD | As Input | I10 | Number of speed profiles for each endurance | |
| | 5 | END | As Input | F10 | NEND values for total mission endurance; in hours | |
| | 6 | CRUZ | As Input | F10 | NSPD values for cruise speed for each mission; in knots | |
| | 7 | DASH | As Input | F10 | NSPD values for dash speed for each mission; in knots | |
| | 8 | PCC | As Input | F10 | NSPD values for percent of total endurance vehicle is cruising | |
| | 9 | NWING | As Input | I10 | Number of identical control surfaces, including forward and rear | See Figure 1. When chord or span vary, use average value. |
| | | WTOC | As Input | F10 | Wing thickness to chord ratio | |
| | | WCBL | As Input | F10 | Wing chord to body length ratio | |
| | | WSWC | As Input | F10 | Wing span to wing chord ratio | |
| | 10 | PRCF | As Input | F10 | Body prismatic coefficient | PRCF = hull displaced volume/[¼ π (BD)$^2$ (BL)] where BD = maximum vehicle diameter and BL = vehicle length. (See Figure 1.) |
| | | BLOD | As Input | F10 | Body length to diameter ratio | |
| | | HVEFF | As Input | F10 | Hull volume efficiency | HVEFF = (sum of component installed volumes)/(hull displaced volume) |
| | | BNWET | As Input | F10 | Body nondimensional wetted area | BNWET = (wetted area)/(vehicle diameter)$^2$ |
| | 11 | VINIT | As Input | F10 | Initial estimate of total installed component volume; in cubic feet | A reasonable estimate will increase speed of convergence. |
| | | VNAV | As Input | F10 | Volume of navigation equipment; in cubic feet | |
| | | VSEN | As Input | F10 | Volume of sensor equipment; in cubic feet | |
| | | VNUT | As Input | F10 | Volume of neutralization equipment, in cubic feet | |
| | | VCD | As Input | F10 | Ratio of control equipment volume to vehicle diameter | |
| | 12 | HTPRT | As Input | F10 | Height of protuberances; in feet | |
| | | CDPRT | As Input | F10 | Individual drag coefficient of protuberance | See Hoerner, Fluid Dynamic Drag, 1965, p. 5-7. |
| | | FPRT | As Input | F10 | Fraction of total wetted area covered by protuberances | |
| | | GSIZM | As Input | F10 | Average sand grain size; in mils | See Hoerner, Fluid Dynamic Drag, 1965, p. 5-3 |
| | 13 | DBRE | As Input | F10 | Density of Brayton engine system | Enter values for Record 13 in lb/cu ft |
| | | DICE | As Input | F10 | Density of internal combustion engine | |
| | | DEME | As Input | F10 | Density of electric motor | |
| | | DFCS | As Input | F10 | Density of fuel cell | |
| | | DLIC | As Input | F10 | Density of LISF6 combustor | Density is based on maximum linear dimensions and not displaced volume |
| (Cont'd) | | DCBC | As Input | F10 | Density of carbon block combustor | |

| FILE | RECORD | INPUT VARIABLE | | | | |
|---|---|---|---|---|---|---|
| | | NAME | VALUE | FORMAT | DESCRIPTION | REMARKS |
| TAPASS/DATA (Cont'd) | 14 | DCON | As Input | F10 | Density of control instrumentation and equipment | Enter values for Records 14 and 15 in lb/cu ft |
| | | DNAV | As Input | F10 | Density of navigation instrumentation and equipment | |
| | | DNUT | As Input | F10 | Density of instrumentation and equipment for neutralizers | Density is based on maximum linear dimensions and not displaced volume. |
| | | DSEN | As Input | F10 | Density of instrumentation and equipment for sensors | |
| | | DHMF | As Input | F10 | Density of hydrogen metal matrix storage system | |
| | | DHLF | As Input | F10 | Density of hydrogen liquid storage | |
| | 15 | DHGF | As Input | F10 | Density of gaseous hydrogen storage | |
| | | DHCF | As Input | F10 | Density of hydrocarbon storage | |
| | | DOXGS | As Input | F10 | Density of oxygen gas storage | |
| | | DOXLS | As Input | F10 | Density of oxygen liquid storage | |
| | | DBTSZ | As Input | F10 | Density of silver zinc battery | |
| | | DBTLI | As Input | F10 | Density of lithium inorganic battery | |
| | 16 | CNAV | As Input | F10 | Cost of navigation equipment | All costs, except CHP, are in thousands of dollars. |
| | | CSEN | As Input | F10 | Cost of sensor equipment | |
| | | CNUT | As Input | F10 | Cost of neutralization equipment | |
| | | CCD | As Input | F10 | Cost per foot vehicle diameter for control equipment | |
| | | CBRE | As Input | F10 | Cost per shp for Brayton engine | |
| | | CBRF | As Input | F10 | Cost per shp for Brayton fuel system | |
| | 17 | CICE | As Input | F10 | Cost per shp for IC engine | |
| | | CSZB | As Input | F10 | Cost per shp-hr of silver zinc battery | |
| | | CLIB | As Input | F10 | Cost per shp-hr of lithium battery | |
| | | CFC | As Input | F10 | Cost per shp for fuel cell | |
| | | CEM | As Input | F10 | Cost per shp for DC motor | |
| | | CHCF | As Input | F10 | Cost per cu ft of hydrocarbon fuel storage | |
| | 18 | CHDG | As Input | F10 | Cost per cu ft of hydrogen gas storage system | |
| | | CHDL | As Input | F10 | Cost per cu ft of hydrogen liquid storage system | |
| | | CHDM | As Input | F10 | Cost per cu ft of hydrogen metal matrix storage system | |
| | | COXG | As Input | F10 | Cost per cu ft of oxygen gas storage system | |
| | | COXL | As Input | F10 | Cost per cu ft of oxygen liquid storage system | |
| | | CHP | As Input | F10 | Cost per lb of hull material | Enter value in dollars. |
| | 19 | DEPF | As Input | F10 | Vehicle operating depth, in feet | |
| | | EPSI | As Input | F10 | Hull material modulus of elasticity, psi | |
| | | SPSI | As Input | F10 | Hull material yield strength, psi | |
| | | DPCF | As Input | F10 | Hull material density, lb/cu ft | |
| | | SF | As Input | F10 | Hull failure safety factor, $\geq$ 1.0 | SF accounts for depths in excess of operating depth, hull penetrations, and hull aberrations. |

(Reverse Page A-4 Blank)

# APPENDIX B

# PROGRAM LISTING

```
TAPSS/WAR6
RECORD =10 WORDS.  BLOCK =30 WORDS.
CREATED: 03/22/78 LISTED: 1755 05/10/78
THE FILE CONTAINS 787 RECORDS.


$SEQXEQ RESET LIST LISTDCL
FILE  3=TAPSS/PRINTER,UNIT=PRINTER,LOCK,RECORD=15
FILE  4=TAPSS/DATA,UNIT=DISK,SAVE=10,BLOCKING=3,RECORD=10
      DIMENSION SHPD(20,20),SHPC(20,20),END(20),DASH(20),CRUZ(20),
     *PCC(20),TITLE(18)
C
C
C  TAPSS--TRADE-OFF ANALYSIS OF PROPULSION SYSTEMS FOR SUBMERSIBLES
C                   R S PETERSON -- MARCH 6, 1978
C
C  PROGRAM WILL COMPUTE SHAFT HORSEPOWER, DIAMETER, COMPONENT VOLUMES,
C  BALLAST LB BUOYANCY, AIR WEIGHT, AND APPROXIMATE DOLLAR COST OF
C  A SERIES OF SMALL, DRY SUBMERSIBLES AS A FUNCTION OF PROPULSION
C  SYSTEM CHARACTERISTICS, VEHICLE GEOMETRY AND SKIN CONDITION,
C  PAYLOAD VOLUME, 40 COMPONENT VOLUME FUNCTIONS, 18 COMPONENT
C  DENSITIES, 15 COMPONENT COST FACTORS, AND A SERIES OF MISSION
C  PROFILES (CRUISE, DASH, PERCENT CRUISE, AND TOTAL ENDURANCE).
C
C
      COMMON RWD,RWC,RBD,RBC,CDWD,CDWC,CDBD,CDBC,CFWD,CFWC,CFBD,CFBC,
     $RPCWD,RPCWC,RPCBD,RPCBC,R,RL,HC,A,CFBAS,CKRUF,CFPRT,CF,
     $IEXT,IREY,DASH,CRUZ,WCHD,VISC,RL,GSIZM,RUF,
     $FPRT,HTPRT,CDPRT,BD,WTDC,WARA,WWFT,J
C
C
C  VOLUME FUNCTIONS
C     ALL VOLUMES IN CU FT.  WTF=WT OF FUEL, LB.  SHPD= SHP,DASH.
C
C     CLOSED CYCLE BRAYTON ENGINE AND DRIVE TRAIN -- 1980
      VBR1(I,J)=0.13*SHPD(I,J)+1.5
C     CLOSED CYCLE BRAYTON ENGINE AND DRIVE TRAIN -- 1985, 1990
      VBR2(I,J)=.08*SHPD(I,J)+1.5
C     CLOSED CYCLE INTERNAL COMBUSTION ENGINE AND DRIVE TRAIN
      VIC(I,J)=0.05*SHPD(I,J)+1.5
C     DC ELECTRIC MOTOR, CONTROLLER, AND DRIVE TRAIN
      VEM(I,J)=0.10*SHPD(I,J)+1.5
C     HYDROGEN LIQUID AND CONTAINMENT
      VHL(WTF)=6.0+0.3*WTF
C     HYDROGEN GAS (3,000 PSI) AND CONTAINMENT
      VHG(WTF)=3.0+0.94*WTF
C     HYDROGEN METAL MATRIX STORAGE SYSTEM
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```
      VHM(WTF)=3.0+.15*WTF
C     HYDROCARBON AND CONTAINMENT
      VHC(WTF)=3.0+.023*WTF
C     CARBON DIOXIDE SCRUBBER
      VSCRB(WTF)=1.0+0.1*WTF
C     BATTERY, LITHIUM INORGANIC
      VBTLI(SHPHR)=0.055*SHPHR
C     BATTERY, SILVER ZINC
      VBTSZ(SHPHR)=0.22*SHPHR
C     FUEL CELL SYSTEM, 1980
      VFC1(I,J)=.33*SHPD(I,J)
C     FUEL CELL SYSTEM, 1985
      VFC2(I,J)=.17*SHPD(I,J)
C     FUEL CELL SYSTEM, 1990
      VFC3(I,J)=.08*SHPD(I,J)
C     OXYGEN FUNCTIONS--SEE SUBROUTINE OXIDZR
C
C  PACKING FACTOR FUNCTIONS
C     PF=(VOL BASED ON MAX DIMENSIONS)/(VOL CONSUMED IN VEHICLE)
C     INDEPENDENT VARIABLES SIGNIFY THE VOL OF THE RESPECTIVE COMPONENT
C
C     BRAYTON ENGINE
      PFBR(VBRE)=0.9*(1.0-EXP(-.3*(VBRE+3.5)))
C     INTERNAL COMBUSTION ENGINE
      PFIC(VICE)=0.9*(1.0-EXP(-.3*(VICE+3.5)))
C     DC ELECTRIC MOTOR
      PFEM(VEME)=0.9*(1.0-EXP(-.3*(VEME+3.5)))
C     LISF6 COMBUSTOR
      PFLI(VLIC)=0.9
C     CARBON BLOCK COMBUSTOR
      PFCB(VCBC)=0.9
C     HYDROGEN LIQUID
      PFHL(VHLF)=.9
C     HYDROGEN GAS
      PFHG(VHGF)=.9
C     HYDROGEN METAL MATRIX
      PFHM(VHMF)=0.9
C     HYDROCARBON
      PFHC(VHCF)=.9
C     BATTERY
      PFBT(VBTS)=.9
C     FUEL CELL
      PFFC(VFSC)=0.9
C     OXYGEN PACKING FACTOR FUNCTIONS: SEE SUBROUTINE OXIDZR
C
C  FUEL CONSUMPTION FUNCTIONS
C     RCD=RATIO OF CRUISE TO DASH SHP
```

```
C
C      WEIGHT (PER HR. TO ENG) OF DASH H2 CONSUMPTION
       WHICH(I,J)=.25*SHPD(I,J)
C      FRACTION (IC ENG, H2, CRUISE) OF DASH CONSUMPTION
       FICH(RCD)=1.0*RCD
C      WEIGHT (PER HR, TO ENG) OF DASH HC CONSUMPTION
       WHICHC(I,J)=0.77*SHPD(I,J)
C      FRACTION (IC ENG, HC, CRUISE) OF DASH CONSUMPTION
       FICHC(RCD)=1.0*RCD
C      WEIGHT OF H2 FOR 1980 FUEL CELL
       WHFC1(SHPHR) 0.11*SHPHR
C      WEIGHT OF H2 FOR 1985 FUEL CELL
       WHFC2(SHPHR)=0.13*SHPHR
C      WEIGHT OF H2 FOR 1990 FUEL CELL
       WHFC3(SHPHR)=0.17*SHPHR
C      VOLUME (PER HR, BRAYTON) OF DASH LISF6 CONSUMPTION
       VFLI(I,J)=.04*SHPD(I,J)
C      VOLUME  (PER HR, BRAYTON) OF DASH CARBON BLOCK CONSUMPTION
       VFCB(I,J)=.0 *SHPD(I,J)
C      FRACTION (LISF6 COMBUSTOR, CRUISE) OF DASH CONSUMPTION
       FLI(RCD)=1.0*RCD
C      FRACTION (CB COMBUSTOR, CRUISE) OF DASH CONSUMPTION
       FCB(RCD)=1.0*RCD
C
C  TIME CALCULATION
C
       MDY=TIME(5)
       XTIME=TIME(1) 216000.0
       NHRS=XTIME
       THRS=XTIME-NHRS
       MIN=THRS*60.0
C
C  FORMAT STATEMENTS
C
22     FORMAT(8F14. 
25     FORMAT("NO HYDROCARBON FOR FUEL CELL")
26     FORMAT (5X,I2,10F8.1,F7.1,F9.1,F6.1,F8. )
27     FORMAT(10F8.1)
28     FORMAT (10F10.1)
29     FORMAT(1H1,/,2X,40H  MSHN  ENDUR   CR SPD  DSH SPD PER CT  ,
      $60H SH HP  SH HP ENG VOL FUEL VOL OX VOL  BALLAST  BODY  AIR WT,
      $14H  VEH DIA COST)
30     FORMAT(42H      NO.    HRS     KNOTS     KNOTS  CRUISE   ,
      $60H CRUISE DASH    CU FT      CU FT  CU FT      LBS    CU FT   LBS ,
      $14H     FT     $K ,/)
35     FORMAT(" DRAGC,DRAGD,SHPC,SHPD,RCD,SHPHR,SHPDH,SHPHRCH")
3      FORMAT (" VENGI,VFUELI,VOXIDI,VNEW,WNEW,COST,LPWI,VINCR")
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41     FORMAT(I10,3F10.3)
44     FORMAT(" VINCH,VWCH,VHULL,BD,BL,WCHD,WSPN,WTHK")
45     FORMAT(//,1X,17HEND,PCC,CRUZ,DASH)
48     FORMAT (5I10)
49     FORMAT (10F10.3)
56     FORMAT (18A4)
59     FORMAT(" WNEW,VBUOY,WENG,WFUEL,WOXID,WCON,WNAV,WSEN,WNUT")
98     FORMAT(/,34X,"***TAPSS/MAR6 ***(",A6,")***",I2,1H/,I2,"***")
391    FORMAT(/////,41X,21HSPEEDS AND ENDURANCES)
392    FORMAT(/,18X,36HMISSION      END, HRS   CRUISE, KNOTS,
      $31H     DASH, KNOTS  PERCENT CRUISE,/)
393    FORMAT(8X,I14,3F14.1,I14)
394    FORMAT(1H1,///,24X,40HTRADE-OFF ANALYSIS OF PROPULSION SYSTEMS,
      $17H FOR SUBMERSIBLES)
401    FORMAT(/,22X,18A4)
402    FORMAT(1H1,/////,10X,29HPROPULSION SYSTEM INFORMATION,/)
403    FORMAT(/,15X,14HELECTRIC MOTOR)
404    FORMAT(15X,28HELECTRIC MOTOR AND FUEL CELL)
405    FORMAT(15X,22HCLOSED CYCLE IC ENGINE)
406    FORMAT(15X,27HCLOSED CYCLE BRAYTON ENGINE)
407    FORMAT(15X,18HHYDROCARBON FUELED)
408    FORMAT(15X,30HHYDROGEN GAS FUELED--3,000 PSI)
409    FORMAT(15X,22HHYDROGEN LIQUID FUELED)
410    FORMAT(15X,28HHYDROGEN METAL MATRIX FUELED)
411    FORMAT(15X,11HAIR DILUTED)
412    FORMAT(15X,14HHELIUM DILUTED)
413    FORMAT(15X,14HGASEOUS OXYGEN)
414    FORMAT(15X,13HLIQUID OXYGEN)
415    FORMAT(15X,15HLITHIUM BATTERY)
416    FORMAT(15X,19HSILVER ZINC BATTERY)
417    FORMAT(15X,15HLISF6 COMBUSTOR)
418    FORMAT(15X,22HCARBON BLOCK COMBUSTOR)
419    FORMAT(15X,16HTIME FRAME--1980)
420    FORMAT(15X,16HTIME FRAME--1985)
421    FORMAT(15X,16HTIME FRAME--1990)
422    FORMAT(/,10X,22HWING AND HULL GEOMETRY)
423    FORMAT(15X,4HNO.=,I2,3X,4HT/C=,F4.2,3X,5HC/BL=,F4.2,3X,4HS/C=,
      $F4.2)
424    FORMAT(15X,11HPRISM COEF=,F6.4,3X,4HL/D=,F5.2,3X,12HHV PACK EFF=,
      $F4.2,3X,12HND WET AREA=,F6.3)
425    FORMAT(/,10X,18HVOLUME INFORMATION)
426    FORMAT(15X,6HVINTT=,F5.1,3X,5HVNAV=,F5.1,3X,5HVSEN=,F5.1,3X,
      $5HVNUT=,F5.1,3X,12HVOL CON/DIA=,F4.1)
427    FORMAT(/,10X,21HROUGHNESS INFORMATION)
428    FORMAT(15X,26HFT, CD, AND FRACT FOR PROT,3F6.3,5X,
      $17HGRAIN SIZE, MILS=,F5.2)
429    FORMAT(/,10X,21HDENSITY OF COMPONENTS)
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430   FORMAT(15X,45HDBRE,DICE,DEMF,DFCS,DLIC,DCBC,DCON,DNAV,DNUT,
     $48HDSEN,DHMF,DHLF,DHGF,DHCF,DOXGS,DOXLS,DBTSZ,DBTLI)
431   FORMAT(15X,18F5.0)
432   FORMAT(/,10X,25HMISCELLANEOUS INFORMATION)
433   FORMAT(15X,10HPROP EFF= ,F4.2,3X,9HINST WTS=,F4.1,3X,
     $11HSW TEMP F= ,F3.0,3X,19HF/O RATIO- HC, H2: ,F4.3,1X,F4.3)
434   FORMAT(/,10X,18HCOST OF COMPONENTS)
435   FORMAT(15X,45HCNAV,CSEN,CNUT, CCD,CBRE,CPMF,CICE,CSZP,CLIB,
     $44H CFC, CEM,CHCF,CHDG,CHDL,CHDM,COXG,COXL, CHP)
436   FORMAT(15X,18F5.1)
437   FORMAT(1H )
438   FORMAT(/,10X,24HVEHICLE HULL INFORMATION)
439   FORMAT(15X,10HDEPTH, FT=,F6.0,3X,21HYOUNGS ELAS MOD, PSI=,
     $F10.0,3X,23HMATL YIELD STRESS, PSI=,F7.0)
440   FORMAT(15X,18HMATL DENSITY, PCF=,F5.0,3X,14HSAFETY FACTOR=,F4.1)
441   FORMAT(" HULT,RIBSP,WHULL,SMTI,NRIB")
442   FORMAT(" CENG,CFUEL,COXID,CCDN,CHULL")
443   FORMAT(" AN UPDATE OF THE BUOYANCY IS REQUIRED")
C
C  INPUT DATA FROM TAPSS/DATA
C
      READ(4,56)(TITLE(I),I=1,18)
      READ(4,48)IENG,IFUEL,IDILU,ICOMB,IOXID
      READ(4,48)IBATT,ITIME,IEXT
      READ(4,49)EPROP,RHC,RHD,PINST,TEMPF
      READ(4,48)NEND,NSPD
      READ(4,49)(END(I),I=1,NEND)
      READ(4,49)(CRU7(I),I=1,NSPD)
      READ(4,49)(DASH(I),I=1,NSPD)
      READ(4,49)(PCC(I),I=1,NSPD)
      READ(4,41)NWING,WTCC,WCBL,WSWC
      READ(4,49)PROP,BLCD,HVEFF,HNWET
      READ(4,49)VINIT,VNAV,VSEN,VNUT,VCD
      READ(4,49)HTPRT,CDPRT,FPRT,GSIZM
      READ(4,49)DBRE,DICE,DEME,DFCS,DLIC,DCBC
      READ(4,49)DCON,DNAV,DNUT,DSEN,DHMF,DHLF
      READ(4,49)DHGF,DHCF,DOXGS,DOXLS,DBTSZ,DBTLI
      READ(4,49)CNAV,CSEN,CNUT,CCD,CBRE,CBRF
      READ(4,49)CICE,CSZP,CLIB,CFC,CEM,CHCF
      READ(4,49)CHDG,CHDL,CHDM,COXG,COXL,CHP
      READ(4,49)DEPF,EPSI,SPSI,DPCF,SF
C
C  OUTPUT INPUT INFORMATION
C
      WRITE(3,394)
C  THE TIME AND TITLE
      WRITE(3,98) MDY,NHRS,MIN
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      WRITE(3,401) (TITLE(I),I=1,18)
C  THE VELOCITY AND ENDURANCE
      WRITE(3,391)
      WRITE(3,392)
      MSHN=0
      DO 601 I=1,NEND
      DO 602 J=1,NSPD
      MSHN=MSHN+1
      WRITE(3,393) MSHN, END(I),CRUZ(J),DASH(J),PCC(J)
602   CONTINUE
601   CONTINUE
C  THE INPUT OPTIONS AND CONSTANTS
      WRITE(3,402)
      GO TO (552,553,554,555), IENG
552   WRITE (3,404)
      IDILU=0
      GO TO 556
553   WRITE (3,403)
      IF (IBATT .EQ. 1) WRITE(3,415)
      IF (IBATT .EQ. 2) WRITE(3,416)
      GO TO 557
554   WRITE(3,405)
      GO TO 556
555   WRITE(3,406)
      IF (ICCMB .EQ. 1) WRITE(3,417)
      IF (ICCMB .EQ. 2) WRITE(3,418)
      GO TO 557
556   IF (IFUEL .EQ. 1) WRITE(3,407)
      IF (IFUEL .EQ. 2) WRITE(3,408)
      IF (IFUEL .EQ. 3) WRITE(3,409)
      IF (IFUEL .EQ. 4) WRITE(3,410)
      IF (IDILU .EQ. 1) WRITE(3,411)
      IF (IDILU .EQ. 2) WRITE(3,412)
      IF (ICXID .EQ. 1) WRITE(3,413)
      IF (ICXID .EQ. 2) WRITE(3,414)
557   IF(ITIME .EQ. 1) WRITE(3,419)
      IF(ITIME .EQ. 2) WRITE(3,420)
      IF(ITIME .EQ. 3) WRITE(3,421)
      WRITE(3,422)
      WRITE(3,423) NWING, WTCC,WCPL,WSWC
      WRITE(3,424) FRCF,FLCD,HVEFF,BNWFT
      WRITE(3,425)
      WRITE(3,426) VINIT,VNAV,VSEN,VNUT,VCD
      WRITE(3,427)
      WRITE(3,428) FTPRT,CDFRT,FFFT,GSIZM
      WRITE(3,429)
      WRITE(3,430)
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      WRITE(3,431) DBRF,DICF,DFMF,DFCS,DLIC,DCBC,DCUN,DNAV,DNUT,
     $DSEN,DHMF,DHLF,DHGF,DHCF,DOXGS,DOXLS,DBTSZ,DBTLI
      WRITE(3,432)
      WRITE(3,433)EPROP,PINST,TEMPF,RHO,RHD
      WRITE(3,434)
      WRITE(3,435)
      WRITE(3,436)CNAV,CSEN,CNUT,CCD,CPRE,CBRF,CICF,CSZB,CLIB,
     $CFC,CEM,CHCF,CHDG,CHDL,CHDM,COXG,COXL,CHP
      WRITE(3,438)
      WRITE(3,439)DEPF,EPSI,SPSI
      WRITE(3,440)DHCF,SF
C
C
C
C   PRELIMINARY CALCULATIONS
C
      VISC=2.6E-9*(TEMPF-100.)**2.+7.5E-6
      PPSI=64.2/144.0*DEPF
      WRITE(3,29)
      WRITE(3,30)
      MSHN=0
C
C   ITERATE ENDURANCE
C
      DO 210 I=1,NEND
C
C   ITERATE SPEED COMBINATION
C
      DO 205 J=1,NSPD
C
      VNEW=VINIT
      MSHN=MSHN+1
      VINCR=0.0
      VBODY=0.0
C
C
C   UPDATE PROPULSION AND PAYLOAD VOLUME
C
C   CALCULATE BODY GEOMETRY
550   VWOHS=VWOH
      VWOH=VNEW+VBODY
      IF(VINCR .LT. 0.0) VWOH=VWOH+(VNEW+VBODY-VWOHS)/2.0
      VHULL=VWOH/HVEFF
      BD=(4.*VHULL/PRCF/PLOD/3.14159)**.333
      BWET=BNWET*BD**2.
      BL=BD*PLOD
C   CALCULATE HULL THICKNESS AND WEIGHT, FAIRES, P. 525
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C      SATISFIES BOTH STRENGTH AND INSTABILITY CRITERIA, BY INCLUDING
C      A NUMBER OF RIBS, EACH WITH A SECTIONAL MOMENT OF INERTIA, SMII
C      EXPRESSED IN INCHES**4
       HULT=SF*PPSI*BD/2.0/SPSI
       RIBSP=BD*(2.60*EPSI*(HULT/BD)**2.5/PPSI/SF+0.45*(HULT/BD)**0.5)
       SMII=0.035*BD**3.0*RIBSP*SF*PPSI/EPSI*12.0**4.0
       NRIB=BL/RIBSP
       WHULL=BWET*HULT*DFCF
C   CALCULATE WING (CONTROL SURFACE) GEOMETRY
       WCHD=WCBL*BL
       WSPN=WSWC*WCHD
       WTHK=WTOC*WCHD
       WARA=WSPN*WCHD
       WWET=2.*WARA
C      **EXTEND**
       IF (IEXT .EQ. 1) GO TO 551
       WRITE(3,45)
       WRITE(3,28)END(I),PCC(J),CRUZ(J),DASH(J)
       WRITE (3,44)
       WRITE(3,22) VINCR, VWDH,VHULL,BD,BL,WCHD,WSPN,WTHK
       WRITE(3,441)
       WRITE(3,22)HULT,RIBSP,WHULL,SMII,NRIB
C      **EXTEND**
551    CONTINUE
C
C
C   CALCULATE DRAG COEFFICIENTS FOR WING AND BODY, FOR BOTH
C      CRUISE AND DASH SPEEDS
C
       CALL DRAG
C
C   PROPULSION SYSTEM SIZING CALCULATION
C
C   DRAG AND POWER REQUIREMENTS
       DRAGC=1.9905/2.*(CRUZ(J)*1.688)**2.*(CDWC*WWET*NWING+CDBC*BWET)
       DRAGD=1.9905/2.*(DASH(J)*1.688)**2.*(CDWD*WWET*NWING+CDBD*BWET)
C      INSTRUMENTATION POWER CALCULATION
       IF(IENG .EQ. 1 .OR. IENG .EQ. 2) GO TO 271
       IF(IENG .EQ. 3 .OR. IENG .EQ. 4) GO TO 272
271    SHPOH=0.0
       SHPHROH=0.0
       GO TO 273
272    SHPOH=2.0*(PINST*1.341)
       SHPHROH=SHPOH*END(I)
273    SHPC(I,J)=DRAGC*CRUZ(J)*1.688/550.0/EPROP+SHPOH
       SHPD(I,J)=DRAGD*DASH(J)*1.688/550.0/EPROP+SHPOH
       RCD=SHPC(I,J)/SHPD(I,J)
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```
      SHPHB=END(I)*(SHPC(I,J)*PCC(J)/100.+SHPL(I,J)*(1.-PCC(J)/100.))
     $+SHPHBCH
C     **EXTEND**
      IF (IEXT .EQ. 1) GO TO 389
      WRITE(3,35)
      WRITE (3,28) DRAGC,DRAGD,SHPC(I,J),SHPD(I,J),HCD,SHPHB,SHPUH,
     $SHPHBLH
C     **EXTEND**
389   GO TO (110,110,120,130),IENG
C  BRAYTON ENGINE VOLUME CALCULATION
130   GO TO (131,132,132), ITIME
131   VBRE=VBR1(I,J)
      GO TO 133
132   VBRE=VBR2(I,J)
133   WENG=DBRE*VBRE
      CENG=CBRE*SHPD(I,J)
      VENGI=VBRE/PFBR(VBRE)
      GO TO 140
C  IC ENGINE VOLUME CALCULATION
120   VICE=VIC(I,J)
      WENG=DICE*VICE
      CENG=CICE*SHPD(I,J)
      VENGI=VICE/PFIC(VICE)
      GO TO 140
C  ELECTRIC MOTOR VOLUME CALCULATION
110   VEME=VEM(I,J)
      WENG=DEME*VEME
      CENG=CEM*SHPD(I,J)
      VENGI=VEME/PFEM(VEME)
C  FUEL SYSTEM CALCULATION
140   GO TO (141,142,143,144), IENG
C  BRAYTON FUEL SYSTEM
144   VOXIDI=0.0
      WOXID=0.0
      COXID=0.0
      GO TO (145,146), ICOMB
C  LITHIUM COMBUSTOR
145   VLIC=END(I)*VFLI(I,J)*((1.-PCC(J)/100.)+
     *FLI(RCD)*PCC(J)/100.)
      WFUEL=DLIC*VLIC
      CFUEL=CBRF*SHPD(I,J)
      VFUELI=VLIC/PFLI(VLIC)
      GO TO 200
C  CARBON BLOCK COMBUSTOR
146   VCBC=END(I)*VFCB(I,J)*((1.-PCC(J)/100.)+
     *FCB(RCD)*PCC(J)/100.)
      WFUEL=DCBC*VCBC
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      CFUEL=CHRF*SHFD(I,J)
      VFUEL1=VCBC/PFCB(VCBC)
      GO TO 200
C  IC FUEL AND OXIDIZER VOLUME CALCULATION
143   GO TO (251,252), IDILU
251   DILFAC=1.0
      GO TO 215
252   DILFAC=0.8
215   GO TO (151,152,153,154), IFUEL
C  IC--HYDROGEN METAL MATRIX AND OXIDIZER (LIQ OR GAS)
154   WTF=WHICH(I,J)*END(I)*((1.-PCC(J)/100.)+
     *FICH(RCD)*PCC(J)/100.)
      WTF=WTF*DILFAC
      VHMF=VHM(WTF)
      WFUEL=DHMF*VHMF
      CFUEL=CHDM*VHMF
      VFUEL1=VHMF/PFHM(VHMF)
      CALL OXIDZR (RHC,RHD,WTF,VOXTOT,TFUEL,TOXID,DOXLS,DOXGS,WOXID,
     $COXID,COXL,COXG)
      GO TO 200
C  IC--HYDROGEN LIQUID AND OXIDIZER (LIQ OR GAS)
153   WTF=WHICH(I,J)*END(I)*((1.-PCC(J)/100.)+
     *FICH(RCD)*PCC(J)/100.)
      WTF=WTF*DILFAC
      VHLF=VHL(WTF)
      WFUEL=DHLF*VHLF
      CFUEL=CHDL*VHLF
      VFUEL1=VHLF/PFHL(VHLF)
      CALL OXIDZR (RHC,RHD,WTF,VOXTOT,TFUEL,TOXID,DOXLS,DOXGS,WOXID,
     $COXID,COXL,COXG)
      GO TO 200
C  IC--HYDROGEN GAS AND OXIDIZER (LIQ OR GAS)
152   WTF=WHICH(I,J)*END(I)*((1.-PCC(J)/100.)+
     *FICH(RCD)*PCC(J)/100.)
      WTF=WTF*DILFAC
      VHGF=VHG(WTF)
      WFUEL=DHGF*VHGF
      CFUEL=CHDG*VHGF
      VFUEL1=VHGF/PFHG(VHGF)
      CALL  OXIDZR(RHC,RHD,WTF,VOXTOT,TFUEL,TOXID,DOXLS,DOXGS,WOXID,
     $COXID,COXL,COXG)
      GO TO 200
C  IC--HYDROCARBON AND OXIDIZER (LIQ OR GAS)
151   WTF=WHICHC(I,J)*END(I)*((1.-PCC(J)/100.)+
     *FICHC(RCD)*PCC(J)/100.)
      WTF=WTF*DILFAC
      VHCF=VHC(WTF)
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      WFUEL=DHCF*VHCF
      CFUEL=CHCF*VHCF
      VFUELI=VHCF/PFHC(VHCF)+VSCRB(WTF)
      CALL OXIDZR(RHC,RHC,WTF,VOXIDI,IFUEL,IOXID,DOXLS,DOXGS,WOXID,
     $COXID,COXL,COXG)
      GO TO 200
C  BATTERY VOLUME, WEIGHT, AND COST (FOR ELECTRIC MOTOR)
142   VOXIDI=0.0
      WOXID=0.0
      COXID=0.0
      SHPHR=SHPHR+FND(I)*PINST*1.341
      GO TO (258,259), IBATT
258   VBTS=VBTLI(SHPHR)
      WFUEL=DBTLI*VBTLI(SHPHR)
      CFUEL=CLIB*SHPHR
      GO TO 257
259   VBTS=VBTSZ(SHPHR)
      WFUEL=DBTSZ*VBTSZ(SHPHR)
      CFUEL=CSZB*SHPHR
257   VFUELI=VBTS/PFBT(VBTS)
      GO TO 200
C  FUEL CELL VOLUME, WEIGHT, AND COST (FOR ELECTRIC MOTOR)
141   SHPD(I,J)=SHPD(I,J)+(PINST*1.341)
      SHPHR=SHPHR+FND(I)*(PINST*1.341)
      GO TO (191,192,193), ITIME
191   VFCS=VFC1(I,J)
      VENGI=VFCS/PFFC(VFCS)+VENGI
      WENG=WENG+DFCS*VFCS
      CENG=CENG+CFC*SHPD(I,J)
      WTF=WHFC1(SHPHR)
      GO TO 194
192   VFCS=VFC2(I,J)
      VENGI=VFCS/PFFC(VFCS)+VENGI
      WENG=WENG+DFCS*VFCS
      CENG=CENG+CFC*SHPD(I,J)
      WTF=WHFC2(SHPHR)
      GO TO 194
193   VFCS=VFC3(I,J)
      VENGI=VFCS/PFFC(VFCS)+VENGI
      WENG=WENG+DFCS*VFCS
      CENG=CENG+CFC*SHPD(I,J)
      WTF=WHFC3(SHPHR)
C  FUEL CELL FUEL VOLUME, WEIGHT, AND COST
194   GO TO (195,196,197,198), IFUEL
195   WRITE (3,25)
      STOP
196   VHGF=VHG(WTF)
```

```
      WFUEL=DHGF*VHGF
      CFUEL=CHDG*VHGF
      VFUELI=VHGF/PFHG(VHGF)
      CALL OXIDZR (RHC,RHD,WTF,VOXIDI,IFUEL,IOXID,DOXLS,DOXGS,WOXID,
     $COXID,COXL,COXG)
      GO TO 200
197   VHLF=VHL(WTF)
      WFUEL=DHLF*VHLF
      CFUEL=CHDL*VHLF
      VFUELI=VHLF/PFHL(VHLF)
      CALL OXIDZR(RHC,RHD,WTF,VOXIDI,IFUEL,IOXID,DOXLS,DOXGS,WOXID,
     $COXID,COXL,COXG)
      GO TO 200
198   VHMF=VHM(WTF)
      WFUEL=DHMF*VHMF
      CFUEL=CHDM*VHMF
      VFUELI=VHMF/PFHM(VHMF)
      CALL OXIDZR (RHC,RHD,WTF,VOXIDI,IFUEL,IOXID,DOXLS,DOXGS,WOXID,
     $COXID,COXL,COXG)
C
C  SUM VOLUMES, WEIGHTS, AND COSTS
C  INCLUDING PROP, CON, SEN, NEUT, AND NAV
C
200   VPROPI=VENGI+VFUELI+VOXIDI
      VCON=BD*VCD
      VNEW=VCON+VNAV+VSEN+VNUT+VPROPI
      WCON=DCON*VCON
      CCON=CCD*BD
      CHULL=CHP*WHULL/1000.0
      WNAV=DNAV*VNAV
      WSEN=DSEN*VSEN
      WNUT=DNUT*VNUT
      WNEW=WENG+WFUEL+WOXID+WCON+WNAV+WSEN+WNUT+WHULL
      COST=CENG+CFUEL+COXID+CCON+CNAV+CSEN+CNUT+CHULL
      DFWT=VHULL*64.2
C
C  CALCULATE VOLUME INCREASE REQUIRED
C
C  IF LARGE, RECALCULATE
C  IF SMALL, CHECK AND ADJUST FOR NEUTRAL BUOYANCY
C  IF NEGATIVE (FROM PREVIOUS CALCULATION), CHECK FOR NEUTRAL
C     BUOYANCY (VWOH=AVG OF LAST TWO CALCULATIONS)
C
      IF(VINCR .LT. 0.0) GO TO 851
      VINCR=(VNEW+VBUOY)-VWOH
C     **EXTEND**
      IF(IEXT .EQ. 1) GO TO 201
```

```
      WRITE(3,442)
      WRITE(3,22)CENG,CFUEL,COXID,CCON,CHULL
      WRITE(3,38)
      WRITE(3,22) VENGT,VFUELI,VOXIDI,VNEW,WNEW,COST,DPWT,VINCR
C     **EXTEND**
201   IF (ABS(VINCR) .GT. (VHULL/100.0)) GO TO 550
C  CHECK FOR NEUTRAL BUOYANCY
8=1   VHOLD=VBUOY
      VINCR=0.0
      VBUOY=WNEW/64.2-VNEW/HVEFF
      IF(VBUOY .LT. 0.0) GO TO 51
      IF ((VBUOY-VHOLD) .LT. (VHULL/100.0)) GO TO 51
C     **EXTEND**
      IF(IEXT .EQ. 1) GO TO 57
      WRITE(3,443)
      WRITE(3,59)
      WRITE(3,27) WNEW,VBUOY,WENG,WFUEL,WOXID,WCON,WNAV,WSEN,WNUT
C     **EXTEND**
57    GO TO 550
C ADJUST FOR NEUTRAL BUOYANCY
51    IF(VBUOY) 91,92,93
91    PLEAD=-(VBUOY*64,2)
      VAIR=0.0
      GO TO 94
92    PLEAD=0.0
      VAIR=0.0
      GO TO 94
93    PLEAD=0.0
      VAIR=VBUOY
C
C  OUTPUT RESULTS
C
94    WRITE (3,26) WSHN,END(I),CHI7(J),DASH(J),FCC(J),SHPC(I,J),
     $SHPD(I,J),VENGI,VFUELI,VOXIDT,PLEAD,VAIR,DPWT,BD,COST
C
C  NEW SPEED
205   CONTINUE
C  NEW ENDURANCE
      WRITE(3,437)
210   CONTINUE
      STOP
      END
C
C
      SUBROUTINE OXIDZR (RHC,RHO,WTF,VOXIDI,TFUEL,TOXID,DOXLS,
     $DOXGS,WOXID,COXID,COXL,COXG)
C
```

```
C  SUBROUTINE CALCULATES INSTALLED VOLUME OF LIQ OR GAS
C  OXIDIZER FOR EACH TYPE OF FUEL
C
C       OXYGEN GAS (3,000 PSI) AND CONTAINMENT
        VOXG(WOX)=3.0+0.067*WOX
C       OXYGEN LIQUID AND CONTAINMENT
        VOXL(WOX)=3.0+0.0179*WOX
C       OXYGEN GAS
        PFOXG(VOXGS)=0.95
C       OXYGEN LIQUID
        PFOXL(VOXLS)=0.95
        GO TO (161,162,162,162), IFUEL
161     WOX=WTF/RHC
        GO TO 170
162     WOX=WTF/RHD
170     GO TO (171,172), IOXID
171     VOXGS=VOXG(WOX)
        WOXID=DOXGS*VOXGS
        COXID=COXG*VOXGS
        VOXID1=VOXGS/PFOXG(VOXGS)
        RETURN
172     VOXLS=VOXL(WOX)
        WOXID=DOXLS*VOXLS
        COXID=COXL*VOXLS
        VOXID1=VOXLS/PFOXL(VOXLS)
        RETURN
        END
C
C
        SUBROUTINE DRAG
C
C  DRAG CALCULATION
C  ALL FINAL COEFFICIENTS CALCULATED WRT/ WETTED AREA
C
        COMMON RWD,RWC,RBD,RBC,CDWD,CDWC,CDBD,CDBC,CFWD,CFWC,CFBD,CFBC,
       $RPCWD,RPCWC,RPCBD,RPCBC,R,RL,WC,A,CFBAS,CFRUF,CFPRT,CF,
       $IEXT,IREY,DASH,CRUZ,WCHD,VISC,BL,GSIZM,RUF,
       $FPRT,HTPRT,CDPRT,BD,WTOC,WARA,WWET,J
881     FORMAT(12X,4F10.4,F10.2,4F10.5)
882     FORMAT(" REYNO NO. FOR BODY IS LAMINAR")
883     FORMAT(1X,45HWD/WC/BD/BC--REYNO      RUF        CFRUF       RC,
       $50H       A           CFBAS       CFRUF       CFPRT       CF)
884     FORMAT(4F11.5)
885     FORMAT(" CFWD,CFWC,CFBD,CFBC")
886     FORMAT(" CDWD,CDWC,CDBD,CDBC")
887     FORMAT(" ERROR--K/L GT 5.E-4")
        DIMENSION CRUZ(20),DASH(20)
```

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```
C
C  CALCULATE WING AND BODY REYNO
C
      RWD=DASH(J)*1.688*WCHD/VISC
      RWC=CHUZ(J)*1.688*WCHD/VISC
      RBD=DASH(J)*1.688*FL/VISC
      RBC=CHUZ(J)*1.688*FL/VISC
C
C  CALCULATE BODY AND WING CF FOR EACH SPEED
C
C     **EXTEND**
      IF (IEXT .EQ. 1) GO TO 358
      WRITE (3,883)
C     **EXTEND**
358   DO 380 IREY=1,4
      GO TO (351,352,353,354),IREY
351   R=RWD
      RL=WCHD
      GO TO 370
352   R=RWC
      RL=WCHD
      GO TO 370
353   R=RBD
      RL=FL
      GO TO 370
354   R=RBC
      RL=FL
C
C  BASE SKIN FRICTION
C
370   RUF=GSIZM/1.2E4/RL
      IF(RUF .LT. 1.0E-6) RUF=1.0E-6
      IF(RUF .GT. 1.0E-4) WRITE (3,887)
      IF(RUF .GT. 1.0E-4) RUF=1.0E-4
      CFRUFF=1.667E-4*(ALOG10(RUF)+8.0)**2.0+0.0017
      RC=1.0E6-RUF*8.0E9
      IF(R .LT. RC) GO TO 371
      IF(R .LT. 1.0E7) GO TO 372
      GO TO 373
C  LAMINAR:  REYNO .LT. RC -- HOERNER, P. 2-4, 2-6
371   CFBAS=1.328/R**.5
      CFRUF=0.0
      CFPRT=0.0
      GO TO 390
C  TRANSITION:  RC .LT. REYNO .LT. 1E7 -- HOERNER, P. 5-1, SCH, P. 21.2
372   A=3594.0*ALOG10(RC)-18415.0
      CFBAS=.455/(ALOG10(R))**2.58-A/R
```

```
      CFPRT=0.0
      IF(CFRUFM .GT. (.455/(ALOG10(R)**2.58))) CFRUF=CFRUFM-CFBAS
      IF(CFRUFM .LE. CFBAS) CFRUF=0.0
      GO TO 390
C  TURBULENT (ABOVE 1.0E7):  INCLUDE PROTUB -- HOERNER, P. 5-1, 5-7
373   CFBAS=.455/(ALOG10(R))**2.58
      IF(CFRUFM .GT. CFBAS) CFRUF=CFRUFM-CFBAS
      IF(CFRUFM .LE. CFBAS) CFRUF=0.0
      CFPRT=1.32*FPRT*CDPRT*(HTPRT/RL)**.333*R**.067
390   CF=CFBAS+CFRUF+CFPRT
C     **EXTEND**
      IF (IEXT .EQ. 1) GO TO 400
      WRITE(3,881)R,RUF,CFRUFM,RC,A,CFBAS,CFRUF,CFPRT,CF
C     **EXTEND**
400   GO TO (361,362,363,364), IREY
C
361   CFWD=CFBAS
C  SAVE CONTRIBUTION OF R & P FOR WING TRANSITION DASH CD CALCULATION
      RPCWD=CF/CFBAS
      GO TO 380
C
362   CFWC=CFBAS
C  SAVE CONTRIBUTION OF R & P FOR WING TRANSITION CRUISE CD CALCULATION
      RPCWC=CF/CFBAS
      GO TO 380
C
363   CFBD=CF
C  SAVE CONTRIBUTION OF R & P FOR BODY TRANSITION DASH CD CALCULATION
      RPCBD=CF/CFBAS
      GO TO 380
C
364   CFBC=CF
C  SAVE CONTRIBUTION OF R & P FOR BODY TRANSITION CRUISE CD CALCULATION
      RPCBC=CF/CFBAS
380   CONTINUE
C
C
C  CALCULATE BODY TOTAL DRAG COEFFICIENTS, GIVEN CFBD AND CFBC,
C  HOERNER, 6-16, 6-17
C
C  CRUISE BODY, TRANS + TURB
      IF (RBC-1.E7) 366,366,365
365   CDBC=CFBC*(1.+1.5*(BD/BL)**1.5+7.*(BD/BL)**3.)
      GO TO 368
366   IF(RBC .LT. 1.E6) WRITE(3,882)
      CDBC=(.001*(ALOG10(RBC)-6.)+.002)*RPCBC
C  DASH BODY, TRANS & TURB
```

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```
368     IF(RBL-1.E7) 450,450,449
449     CDBD=CFBD*(1.+1.5*(BD/BL)**1.5+7.*(BD/BL)**3.)
        GO TO 451
450     IF(RBL .LT. 1.E6) WRITE(3,882)
        CDBD=(.001*(ALOG10(RBD)-6.)+.002)*RPCBD
C
C   CALCULATE WING TOTAL DRAG COEFFICIENTS
C
C   CALCULATE WING TOTAL CRUISE DRAG, GIVEN CFWC
451     IF (RWC .LT. 1.E5) GO TO 382
        IF (RWC .LT. 1.E6) GO TO 381
C   TURBULENT--HOERNER, 6-6
        CDWC=WARA/WWET*2.*CFWC*(1.+2.*WTOC+60.*WTOC**4.)
        GO TO 383
C   TRANSITION--CURVE FIT TO HOERNER, 6-2
C   INCLUDE RUF AND FROT FROM CFWC CALCULATION
381     CDWC=WARA/WWET*10.**((.16+2.67*WTOC)*(ALOG10(RWC)-6.)**2.+
       *ALOG10(.0034+.0227*WTOC))*RPCWC
        GO TO 383
C   LAMINAR--HOERNER, 6-5
382     CDWC=WARA/WWET*(2.*CFWC*(1.0+WTOC)+WTOC**2.0)
C   CALCULATE WING TOTAL DASH DRAG, GIVEN  CFWD
383     IF (RWD .LT. 1.E5) GO TO 385
        IF (RWD .LT. 1.E6) GO TO 386
        CDWD=WARA/WWET*2.0*CFWD*(1.0+2.0*WTOC+60.0*WTOC**4.0)
        GO TO 387
386     CDWD=WARA/WWET*10.**((.16+2.67*WTOC)*(ALOG10(RWD)-6.)**2.+
       *ALOG10(.0034+.0227*WTOC))*RPCWC
        GO TO 387
385     CDWD=WARA/WWET*(2.0*CFWD*(1.0+WTOC)+WTOC**2.0)
387     CONTINUE
C       **EXTEND**
        IF (IEXT .EQ. 1) GO TO 388
        WRITE(3,885)
        WRITE(3,884)CFWD,CFWC,CFBD,CFBC
        WRITE(3,886)
        WRITE(3,884)CDWD,CDWC,CDBD,CDBC
C       **EXTEND**
388     CONTINUE
        RETURN
        END
```

# APPENDIX C

# SAMPLE EXECUTION

TRADE-OFF ANALYSIS OF PROPULSION SYSTEMS FOR SUBMERSIBLES

***TAPSS/MAR6 ***(041278)***15:59***

IC ENGINE, LIQUID FUELED 3 APR 78

SPEEDS AND ENDURANCES

| MISSION | END, HRS | CRUISE, KNOTS | DASH, KNOTS | PERCENT CRUISE |
|---|---|---|---|---|
| 1 | 6.0 | 2.0 | 4.0 | 0 |
| 2 | 6.0 | 3.0 | 6.0 | 0 |
| 3 | 6.0 | 4.0 | 8.0 | 0 |
| 4 | 6.0 | 5.0 | 10.0 | 0 |
| 5 | 6.0 | 6.0 | 12.0 | 0 |
| 6 | 6.0 | 7.0 | 14.0 | 0 |
| 7 | 8.0 | 2.0 | 4.0 | 0 |
| 8 | 8.0 | 3.0 | 6.0 | 0 |
| 9 | 8.0 | 4.0 | 8.0 | 0 |
| 10 | 8.0 | 5.0 | 10.0 | 0 |
| 11 | 8.0 | 6.0 | 12.0 | 0 |
| 12 | 8.0 | 7.0 | 14.0 | 0 |
| 13 | 10.0 | 2.0 | 4.0 | 0 |
| 14 | 10.0 | 3.0 | 6.0 | 0 |
| 15 | 10.0 | 4.0 | 8.0 | 0 |
| 16 | 10.0 | 5.0 | 10.0 | 0 |
| 17 | 10.0 | 6.0 | 12.0 | 0 |
| 18 | 10.0 | 7.0 | 14.0 | 0 |
| 19 | 12.0 | 2.0 | 4.0 | 0 |
| 20 | 12.0 | 3.0 | 6.0 | 0 |
| 21 | 12.0 | 4.0 | 8.0 | 0 |
| 22 | 12.0 | 5.0 | 10.0 | 0 |
| 23 | 12.0 | 6.0 | 12.0 | 0 |
| 24 | 12.0 | 7.0 | 14.0 | 0 |
| 25 | 14.0 | 2.0 | 4.0 | 0 |
| 26 | 14.0 | 3.0 | 6.0 | 0 |
| 27 | 14.0 | 4.0 | 8.0 | 0 |
| 28 | 14.0 | 5.0 | 10.0 | 0 |
| 29 | 14.0 | 6.0 | 12.0 | 0 |
| 30 | 14.0 | 7.0 | 14.0 | 0 |

```
PROPULSION SYSTEM INFORMATION

     CLOSED CYCLE IC ENGINE
     HYDROGEN LIQUID FUELED
     AIR DILUTED
     LIQUID OXYGEN
     TIME FRAME--1985

WING AND HULL GEOMETRY
     NO.= 8   T/C=0.20    B/BL=0.10    S/C=1.00
     PRISM COFF=0.6835    L/D= 5.27    HV PACK EFF=0.90    ND WET AREA=13.174

VOLUME INFORMATION
     VINIT= 30.0    VNAV=  3.0    VSEN= 13.0    VNUT=  0.0    VOL CON/DIA= 0.5

ROUGHNESS INFORMATION
     HT, CD, AND FRACT FOR PROT 0.003 0.500 0.005      GRAIN SIZE, MILS= 0.10

DENSITY OF COMPONENTS
     DBRE,DICF,DEME,DFCS,DLIC,DCBC,DCON,DNAV,DNUT,DSEN,DHMF,DHLF,DHGF,DHCF,DOXGS,DOXLS,C
       53.  64. 100.  80.  70.  70.  50.  40.  60.  40.  94.  23.  47.  60.  50.  60. 11

MISCELLANEOUS INFORMATION
     PROP EFF= 0.80    INST WTS= 2.5    SW TEMP F= 50.    F/O RATIO- HC, H2: .280 .125

COST OF COMPONENTS
     CNAV,CSEN,CNUT, CCD,CBRE,CBRF,CICE,CSZB,CLIB, CFC, CEM,CHCF,CHDG,CHDL,CHDM,COXG,COX
     150.0300.0 75.0  6.0  0.5  0.5  0.5  0.7  0.3 27.0  0.2  1.0  2.0  3.0  3.0  2.0

VEHICLE HULL INFORMATION
     DEPTH, FT= 1000.    YOUNGS ELAS MOD, PSI= 30000000.    MATL YIELD STRESS, PSI= 80000.
     MATL DENSITY, PCF= 490.    SAFETY FACTOR= 1.5
```

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| MSHN NO. | ENDUR HRS | CR SPD KNOTS | DSH SPD KNOTS | PER CT CRUISE | SH HP CRUISE | SH HP DASH | ENG VOL CU FT | FUEL VOL CU FT | OX VOL CU FT | BALLAST LBS | BUOY CU FT | AI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 6.0 | 2.0 | 4.0 | 0.0 | 6.7 | 6.9 | 2.6 | 10.1 | 4.7 | 807.3 | 0.0 | 2 |
| 2 | 6.0 | 3.0 | 6.0 | 0.0 | 6.8 | 7.5 | 2.6 | 10.4 | 4.8 | 819.4 | 0.0 | 2 |
| 3 | 6.0 | 4.0 | 8.0 | 0.0 | 6.9 | 8.9 | 2.7 | 11.1 | 5.2 | 850.6 | 0.0 | 2 |
| 4 | 6.0 | 5.0 | 10.0 | 0.0 | 7.2 | 11.1 | 2.8 | 12.2 | 5.7 | 896.5 | 0.0 | 2 |
| 5 | 6.0 | 6.0 | 12.0 | 0.0 | 7.6 | 14.7 | 3.0 | 14.0 | 6.5 | 973.9 | 0.0 | 2 |
| 6 | 6.0 | 7.0 | 14.0 | 0.0 | 8.4 | 20.2 | 3.3 | 16.8 | 7.7 | 1093.2 | 0.0 | 3 |
| 7 | 8.0 | 2.0 | 4.0 | 0.0 | 6.7 | 6.9 | 2.6 | 11.3 | 5.2 | 856.2 | 0.0 | 2 |
| 8 | 8.0 | 3.0 | 6.0 | 0.0 | 6.8 | 7.5 | 2.6 | 11.7 | 5.4 | 873.0 | 0.0 | 2 |
| 9 | 8.0 | 4.0 | 8.0 | 0.0 | 6.9 | 9.0 | 2.7 | 12.6 | 5.9 | 912.9 | 0.0 | 2 |
| 10 | 8.0 | 5.0 | 10.0 | 0.0 | 7.2 | 11.3 | 2.8 | 14.2 | 6.6 | 980.8 | 0.0 | 2 |
| 11 | 8.0 | 6.0 | 12.0 | 0.0 | 7.6 | 15.2 | 3.1 | 16.8 | 7.7 | 1092.2 | 0.0 | 3 |
| 12 | 8.0 | 7.0 | 14.0 | 0.0 | 8.5 | 21.4 | 3.4 | 20.9 | 9.6 | 1266.3 | 0.0 | 3 |
| 13 | 10.0 | 2.0 | 4.0 | 0.0 | 6.7 | 6.9 | 2.6 | 12.4 | 5.8 | 905.3 | 0.0 | 2 |
| 14 | 10.0 | 3.0 | 6.0 | 0.0 | 6.8 | 7.5 | 2.6 | 12.9 | 6.0 | 927.2 | 0.0 | 2 |
| 15 | 10.0 | 4.0 | 8.0 | 0.0 | 7.0 | 9.0 | 2.7 | 14.2 | 6.6 | 978.8 | 0.0 | 2 |
| 16 | 10.0 | 5.0 | 10.0 | 0.0 | 7.2 | 11.6 | 2.8 | 16.3 | 7.5 | 1068.4 | 0.0 | 3 |
| 17 | 10.0 | 6.0 | 12.0 | 0.0 | 7.8 | 15.7 | 3.1 | 19.8 | 9.1 | 1218.3 | 0.0 | 3 |
| 18 | 10.0 | 7.0 | 14.0 | 0.0 | 8.7 | 22.6 | 3.5 | 25.5 | 11.7 | 1459.2 | 0.0 | 4 |
| 19 | 12.0 | 2.0 | 4.0 | 0.0 | 6.7 | 6.9 | 2.6 | 13.6 | 6.3 | 954.5 | 0.0 | 2 |
| 20 | 12.0 | 3.0 | 6.0 | 0.0 | 6.8 | 7.5 | 2.6 | 14.2 | 6.6 | 981.8 | 0.0 | 2 |
| 21 | 12.0 | 4.0 | 8.0 | 0.0 | 7.0 | 9.1 | 2.7 | 15.8 | 7.3 | 1046.0 | 0.0 | 3 |
| 22 | 12.0 | 5.0 | 10.0 | 0.0 | 7.2 | 11.8 | 2.9 | 18.4 | 8.5 | 1159.4 | 0.0 | 3 |
| 23 | 12.0 | 6.0 | 12.0 | 0.0 | 7.9 | 16.3 | 3.1 | 23.0 | 10.5 | 1349.7 | 0.0 | 3 |
| 24 | 12.0 | 7.0 | 14.0 | 0.0 | 8.6 | 23.8 | 3.5 | 30.5 | 13.9 | 1671.5 | 0.0 | 4 |
| 25 | 14.0 | 2.0 | 4.0 | 0.0 | 6.7 | 7.0 | 2.6 | 14.8 | 6.8 | 1003.8 | 0.0 | 2 |
| 26 | 14.0 | 3.0 | 6.0 | 0.0 | 6.8 | 7.6 | 2.6 | 15.5 | 7.2 | 1036.9 | 0.0 | 3 |
| 27 | 14.0 | 4.0 | 8.0 | 0.0 | 7.0 | 9.2 | 2.7 | 17.4 | 8.0 | 1114.5 | 0.0 | 3 |
| 28 | 14.0 | 5.0 | 10.0 | 0.0 | 7.3 | 12.0 | 2.9 | 20.7 | 9.5 | 1253.7 | 0.0 | 3 |
| 29 | 14.0 | 6.0 | 12.0 | 0.0 | 7.9 | 15.8 | 3.1 | 26.3 | 12.0 | 1491.6 | 0.0 | 4 |
| 30 | 14.0 | 7.0 | 14.0 | 0.0 | 9.0 | 25.2 | 3.6 | 36.1 | 16.5 | 1904.5 | 0.0 | 5 |

```
TAPSS/DICL
RECORD =10 WORDS.  BLOCK =30 WORDS.
CREATED: 03/22/78 LISTED: 1756 05/10/78
THE FILE CONTAINS 20 RECORDS.


    IC ENGINE, LIQUID FUELED  3 APR 78                                        00000000
         3          3          1          2          2                        00000010
         2          2          1                                              00000020
      0.80       0.26      0.125        2.5       50.0                        00000030
         5          6                                                         00000040
       6.0        8.0       10.0       12.0       14.0                        00000050
       2.0        3.0        4.0        5.0        6.0        7.0             00000060
       4.0        6.0        8.0       10.0       12.0       14.0             00000070
       0.0        0.0        0.0        0.0        0.0        0.0             00000080
         8        0.2        0.1        1.0                                   00000090
     .6835       5.27        0.9     13.174                                   00000100
      30.0        3.0       13.0        0.0        0.5                        00000110
     0.003        0.5      0.005        0.1                                   00000120
      53.0       64.0      100.0       80.0       70.0       70.0             00000130
      50.0       40.0       60.0       40.0       94.0       23.0             00000140
      47.0       60.0       50.0       60.0      110.0      112.0             00000150
     150.0      300.0       75.0        6.0        0.5        0.5             00000160
       0.5        0.7        0.3       27.0        0.2        1.0             00000170
       2.0        3.0        3.0        2.0        3.0       20.0             00000180
   1000.030000000.0      80000.0      490.0        1.5                        00000190
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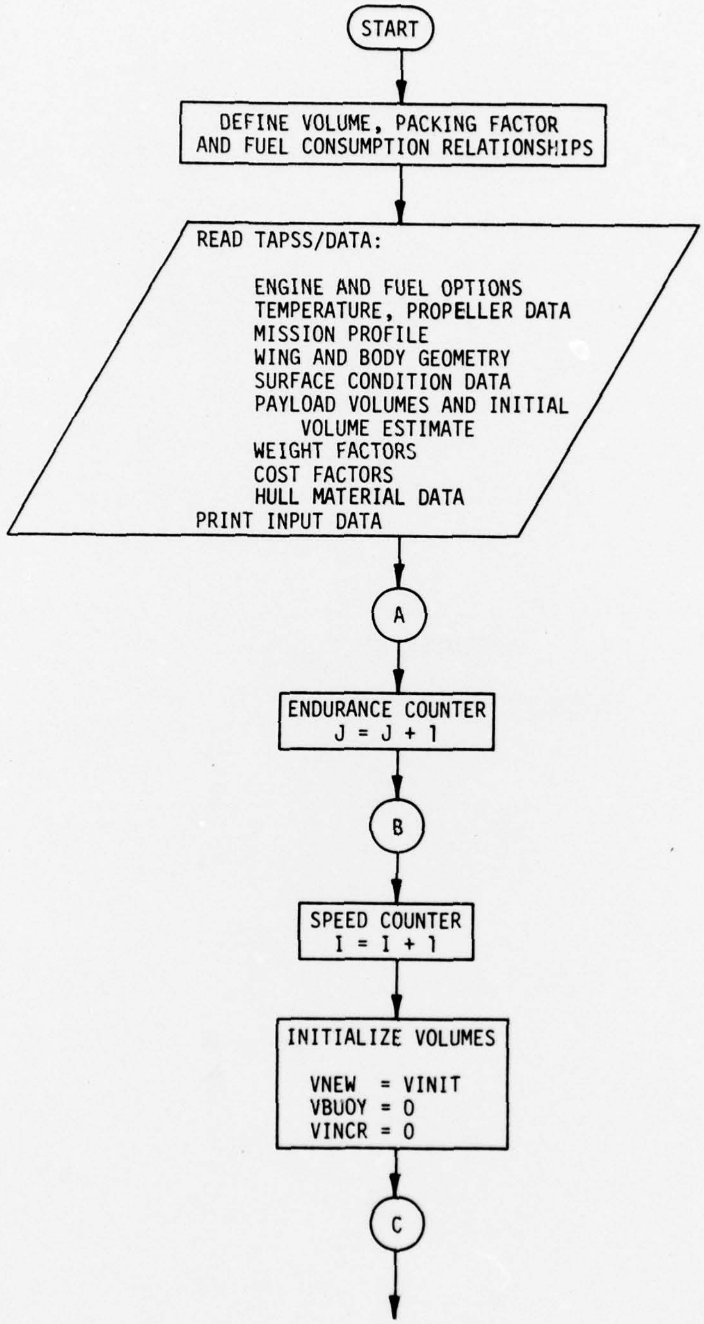
# APPENDIX D

# TAPSS PROGRAM FLOW CHART


START
DEFINE VOLUME, PACKING FACTOR AND FUEL CONSUMPTION RELATIONSHIPS
READ TAPSS/DATA:
ENGINE AND FUEL OPTIONS
TEMPERATURE, PROPELLER DATA
MISSION PROFILE
WING AND BODY GEOMETRY
SURFACE CONDITION DATA
PAYLOAD VOLUMES AND INITIAL VOLUME ESTIMATE
WEIGHT FACTORS
COST FACTORS
HULL MATERIAL DATA
PRINT INPUT DATA
A
ENDURANCE COUNTER
J = J + 1
B
SPEED COUNTER
I = I + 1
INITIALIZE VOLUMES
VNEW = VINIT
VBUOY = 0
VINCR = 0
C

↓

**UPDATE PROPULSION AND PAYLOAD VOLUME**

VOLUME WITHOUT HULL
VWOH = VNEW + VBUOY

HULL DISPLACED VOLUME
VHULL = VWOH/HVEFF

↓

**CALCULATE VEHICLE GEOMETRY**

BODY DIAMETER AND LENGTH
BD= f(VHULL,PRCF,BLOD)
BL= f(BD,BLOD)
WING GEOMETRY
HULL CONSTRUCTION & WEIGHT

↓

**DRAG CALCULATION**

CALCULATE DRAG COEFFICIENT FOR EACH SPEED, FOR WING AND BODY - (CDWC,CDWD,CDBC,CDBD)

↓

**HORSEPOWER CALCULATION**

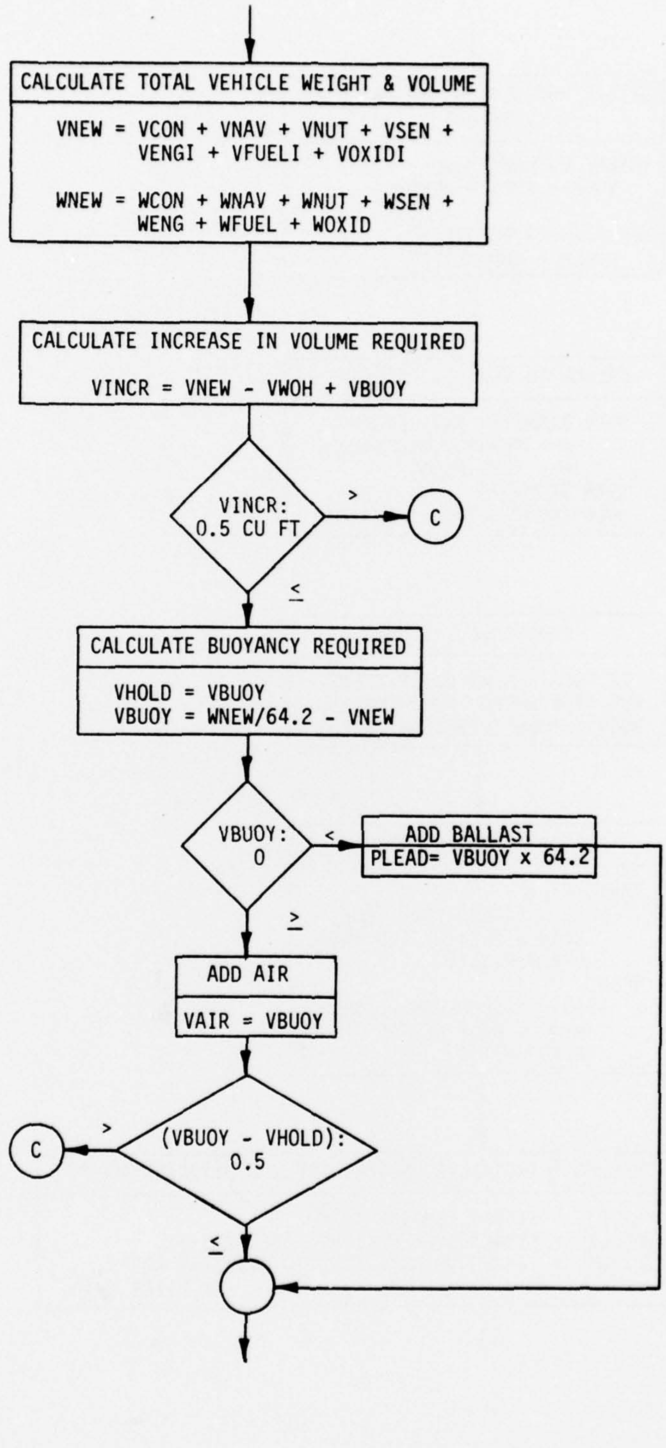
CRUISE:
SHPC = f(CDBC,CDWC,CRUZ, WING & BODY WETTED AREA, EPROP,PINST)
DASH:
SHPD = f(CDBD,CDWD,DASH, WING & BODY WETTED AREA, EPROP,PINST)

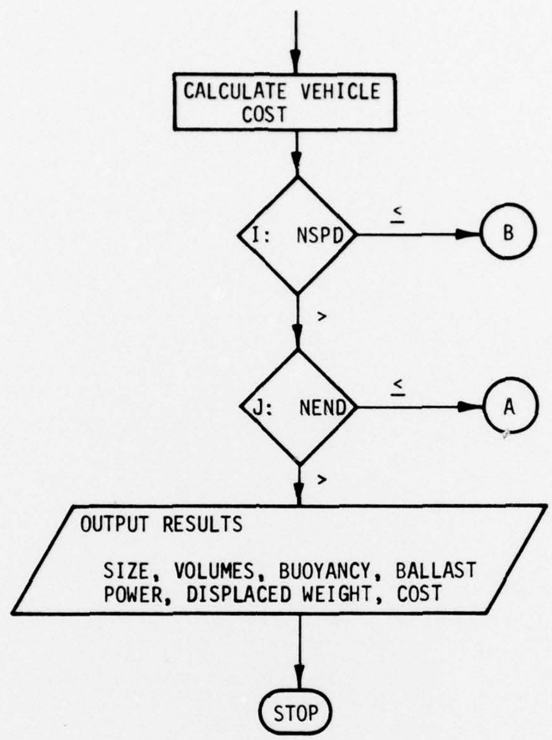
↓

**CALCULATE INSTALLED ENGINE, FUEL, & OXIDIZER VOLUMES**

VENGII = f(SHPD, ENGINE DATA)
VFUELI = f(SHPD,SHPC,PCC,END, FUEL DATA)
VOXIDI = f(FUEL WEIGHT, FUEL TO OXIDIZER RATIO, OXIDIZER DATA)

↓


CALCULATE TOTAL VEHICLE WEIGHT & VOLUME
VNEW = VCON + VNAV + VNUT + VSEN + VENGI + VFUELI + VOXIDI
WNEW = WCON + WNAV + WNUT + WSEN + WENG + WFUEL + WOXID
CALCULATE INCREASE IN VOLUME REQUIRED
VINCR = VNEW - VWOH + VBUOY
VINCR: 0.5 CU FT
>
C
≤
CALCULATE BUOYANCY REQUIRED
VHOLD = VBUOY
VBUOY = WNEW/64.2 - VNEW
VBUOY: 0
<
ADD BALLAST
PLEAD= VBUOY x 64.2
≥
ADD AIR
VAIR = VBUOY
(VBUOY - VHOLD): 0.5
>
C
≤


CALCULATE VEHICLE COST
I: NSPD
≤
B
>
J: NEND
≤
A
>
OUTPUT RESULTS
SIZE, VOLUMES, BUOYANCY, BALLAST
POWER, DISPLACED WEIGHT, COST
STOP

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